REVISION OF THE STANDARD FOR ROAD LIGHTING IN JAPAN

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ABSTRACT

The "Standard for Road Lighting" was thoroughly revised in September 2007. This revision was aimed mainly at defining performance-related provisions. The National Institute for Land, infrastructure Management in Japan (NILIM) participated in preparing the preliminary drafts of the standard in cooperation with some road administrators and some company of industrial road lighting. In addition, verification experiments were conducted to obtain the recommended illuminance values necessary for appropriate administration of the standard to intersection lighting as well as sidewalk lighting, which were newly standardized, and the results were reflected in the standard descriptions.

The three major changes in this revision are:
1) a shift from specifications-based to performance-based requirements;
2) the addition of standards and descriptors for intersection lighting and sidewalk lighting; and
3) the introduction of new theories and technologies on tunnel lighting.

This report describes the revisions to the Standard and the results of verification experiments by NILIM.

1. INTRODUCTION

The standards document Standard for Road Lighting (Head of Road Bureau & Head of City and Regional Development Bureau, Ministry of Land, Infrastructure, Transport and Tourism) was revised in September 2007. A detailed accompanying commentary, Standard for Road Lighting Explanation [1], was revised in October 2007, and it was published by the Japan Road Association.

The revision was the first to be conducted in 26 years, the last revision being in 1981. During this period, road lighting systems have become far more efficient, thanks to improvements in lighting technology as well as higher-powered light sources and more advanced light distribution control systems. Also, there is an increasing emphasis in Japan on universal design principles to facilitate the movement of people with reduced mobility, particularly elderly and disabled persons. The revision of the Standard was undertaken in response to these changes.

This Report describes the major changes in the revised Standard for Road Lighting, as well as the studies and experiments performed by NILIM in relation to the revisions.

2. Major changes in the revised Standard for Road Lighting

The three major changes to this revision are 1) a shift from specifications-based to performance-based requirements, 2) the addition of standards and descriptors for intersection lighting and sidewalk lighting; and 3) the introduction of new theories and technologies on tunnel lighting.

This section explains each of these changes in turn.

2.1 Shift to performance-based requirements

Recent years have seen the development of road lights featuring high-efficiency light sources together with more efficient light distribution systems in Japan. In response to these technological advances, the underlying foundation of lighting standards for ordinary roads “continuous lighting” and tunnels “basic lighting of tunnel lighting” has been shifted from specifications-based to performance-based requirements. The previous Standard set out detailed specifications for parameters such as the type of light source, the height of the light fixture, and the intervals between light fixtures. The new standard stipulates four principal criteria:

- Average road surface luminance (the average level of luminance required at the road surface)
- Luminance uniformity ratio (the degree of uniformity of brightness)
- Disability glare (the impact of glare—usually from a light source—on visibility)
- Guidance (the level of guidance provided to vehicles by continuous light fixtures)

2.1.1 Performance-based requirements for continuous lighting

This section describes criteria for continuous lighting on ordinary roads. Table 1 shows details of the new Standard. Table 2 shows compare the old and new Standards.

Average road surface luminance values are defined for each combination of road type (national expressway etc. versus ordinary national highway etc. (comprising major arterial roads and arterial roads/secondary roads)) and external conditions (denoted A, B and C). The resulting three standard values are 1.0 cd/m^2, 0.7 cd/m^2 and 0.5 cd/m^2. These values are designed to satisfy two key conditions: adequate road surface luminance to enable visual identification of obstacles, and adequate average road surface luminance to enable confirmation of the absence of obstacles when no obstacle is visible in the forward direction. The specifications set out in the old Standard are based on the same principles and the same standard values.

The luminance uniformity ratio is defined as an overall uniformity ratio of no less than 0.4. The overall uniformity ratio is equal to the minimum luminance divided by the average road surface luminance, as shown in Equation 1. Whereas the old Standard set out detailed specifications for parameters such as the height of and spacing between light fixtures (placement of light fixtures, Light distribution from light fixtures), the new Standard simply stipulates the luminance uniformity ratio, thereby allowing greater freedom in the configuration of light fixtures.

$$U_0 = \frac{L_{min}}{L_r} \qquad \text{(Equation 1)}$$

L_{min} = *minimum luminance (cd/m²)*
L_r = *average road surface luminance (cd/m²)*

Photo 1 Continuous lighting

Table 1 Performance-based standards for continuous lighting [Standard for Road Lighting]

(1) Average road surface luminance

• For each combination of road type and external conditions, the figure shown in the upper level of the row represents the basic standard requirement.
• For national expressways designated for automobile traffic only, the figure in the lower level of the row may be used.
• For national highways equipped with fencing or equivalent on the median strip to prevent glare from oncoming vehicles, the figure in the lower level of the row may be used.
• On roads of particular importance and roads affected by exceptional conditions or circumstances, the figure in the table may be disregarded and increased up to a maximum of 2 cd/m^2.

Road type \ External conditions		A	B	C
National expressways etc		1.0 cd/㎡	1.0 cd/㎡	0.7 cd/㎡
		-	0.7 cd/㎡	0.5 cd/㎡
National highways etc	Major arterial roads	1.0 cd/㎡	0.7 cd/㎡	0.5 cd/㎡
		0.7 cd/㎡	0.5 cd/㎡	-
	Arterial roads and secondary roads	0.7 cd/㎡	0.5 cd/㎡	0.5 cd/㎡
		0.5 cd/㎡	-	-

Key to external conditions
A: light affecting road traffic is continuous
B: light affecting road traffic is intermittent
C: little or no light affecting road traffic

(2) Luminance uniformity ratio
• The overall uniformity ratio should normally be at least 0.4.

(3) Disability glare
• The relative threshold increment should normally be no greater than the figure given in the table.

Road type		Relative threshold increment
National expressway etc		Maximum 10%
National highways etc	Major arterial roads	Maximum 15%
	Arterial roads and secondary roads	

(4) Guidance
• Refers to parameters such as height, configuration and spacing of light fixtures to provide an appropriate level of guidance to vehicles.

Table 2 Key differences between the new and old Standard

	Old Standard	New Standard
Stipulations on brightness	Average road surface luminance	Average road surface luminance
	Placement of light fixtures (height, spacing, placement pattern)	luminance uniformity ratio
Stipulations on disability glare	Light distribution from light fixtures	Glare (relative threshold increment)
Stipulations on guidance	No standard	Guidance

Disability glare (the effect of glare on visibility) is stipulated in terms of the relative threshold increment. The relative threshold increment is defined as the negative effect of glare (a bright light source or similar) in the field of vision on visibility, and is expressed as shown in Equation 2. The relative threshold increment is a ratio expressing the increase in the luminance differential between an object and the background road surface when glare is present, compared to the corresponding luminance differential when no glare is present. A lower relative threshold increment means that obstacles are easier to see. The Standard stipulates a maximum relative threshold increment of 10% for national expressways etc., and 15% for ordinary national highways etc. Whereas the old Standard employed light distribution parameters known as cut-off and semi cut-off, the new Standard stipulates only the glare requirement, thereby allowing the use of advanced light fixtures with superior light distribution characteristics.

$$TI = \frac{\Delta L_{min}' - \Delta L_{min}}{\Delta L_{min}} \qquad \text{(Equation 2)}$$

$\Delta L_{min}'$ = luminance differential between object and background required in order to identify the object, in presence of glare

ΔL_{min} = luminance differential between object and background required in order to identify the object, without glare

Guidance refers to stipulations on parameters such as height, configuration and spacing of light fixtures designed to provide vehicle drivers with an appropriate level of guidance. While the concept of guidance does not lend itself to definition and evaluation via quantitative indicators, it nevertheless represents a key requirement of the Standard.

2.1.2 Performance-based requirements for tunnel lighting

Table 3 shows standard values for tunnel lighting. The standard values for luminance uniformity ratio, disability glare and guidance are the same as those for continuous lighting. The average road surface luminance value is based on the objective of being able to identify an obstacle or other object at a distance corresponding to the speed. Thus, the standard value differs according to the design speed.

Table 3 Performance-based standards for tunnel lighting [Standard for Road Lighting]

(1) Average road surface luminance
• The table shows the standard values for each design speed.
• The value shown in the table may be further reduced, depending on traffic volume and tunnel length, but may not be less than 0.7 cd/m^2.

Design speed (km/h)	Average road surface luminance (cd/m^2)
100	9.0
80	4.5
70	3.2
60	2.3
50	1.9
Less than 40	1.5

(2) Luminance uniformity ratio
• The overall uniformity ratio should normally be at least 0.4.
(3) Disability glare
• The relative threshold increment should normally be no greater than 15%.
(4) Guidance
• Parameters such as height, configuration and spacing of light fixtures designed to provide an appropriate level of guidance to vehicles.

The transition to performance-based requirements allows the use of more efficient lighting systems and new technology that reduces the required number of lighting fixtures, thereby enabling genuine cost savings.

2.2 Continuous lighting and local lighting

In conjunction with the transition to performance-based specifications, three further revisions have been introduced to the requirements for continuous and local lighting (defined as lighting installations at specific locations such as intersections and bridges):
(1) Review of criteria for installation;
(2) Addition of recommended values for lighting brightness at intersections; and
(3) Addition of standards of sidewalk lightings.

2.2.1 Review of criteria for installation

Under the old Standard, vehicle traffic volume was used as the criterion for installation of continuous lighting on national highways. The Standard normally required continuous lighting on all roads in urban areas with daily traffic volume of at least 25,000 vehicles, on the basis that the installation of lighting on heavily used roads should help to reduce the incidence of traffic accidents at night. The new Standard takes a different approach: the criterion for installation of lighting is predicated on traffic safety, taking into consideration the potential for situations such as pedestrians crossing the road and vehicles deviating from the marked lanes.

The new Standard also introduces requirements for local lighting on sidewalks and at rest facilities such as station of highways (parking area). Table 4 shows the criteria given in the Standard.

Table 4 Lighting installation criteria on ordinary national highways [Standard for Road Lighting]

(1) Continuous lighting
• Installation of lighting is recommended on sections of road in urban areas that fall in the following categories:
a. Sections of road which pedestrians tend to cross, and which carry a high volume of vehicle and/or pedestrian traffic;
b. Sections of road where vehicles may deviate from the marked lanes, and which carry a high volume of vehicle traffic; and
c. Other sections of road having special conditions or circumstances.

(2) Local lighting
• Road lighting is required at the following locations as a general rule:
a. Intersections and pedestrian crossings equipped with traffic signals
b. Large bridges
c. Locations considered particularly dangerous due to night-time traffic

• Road lighting may be required at the following locations depending on the circumstances:
a. Intersections and pedestrian crossings
b. Sidewalks, etc.
c. Places where the roadway width and/or course changes abruptly
d. Bridges
e. Railway level crossings
f. Sections of road linked to public facilities such as open spaces in front of railway stations
g. Bus stops
h. Toll collection points
i. Rest facilities (such as roadside rest areas)
j. Other locations having special conditions or circumstances

2.2.2 Recommended brightness of intersection lighting

The old Standard did not stipulate the required brightness of lighting at intersections. The only stipulations were those regarding the location of light fixtures in Standard for Road Lighting Explanation. The new Standard for Road Lighting Explanation nominates a recommended value for average road surface illuminance from intersection lighting of approximately 20 Lx together with an illuminance uniformity ratio of approximately 0.4. For intersections with low traffic volume that are located in low-light environments, the recommended average road surface illuminance value is 10 Lx. The new Standard also adds stipulations on lighting installation patterns for corner cut-aways at intersections. Table 5 provides details from the new Standard for Road Lighting Explanation.

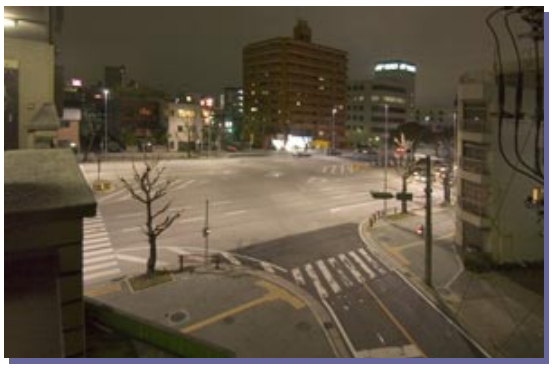
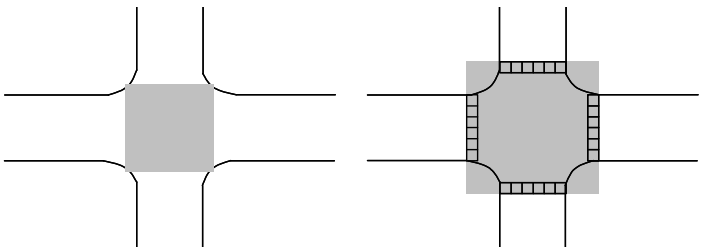


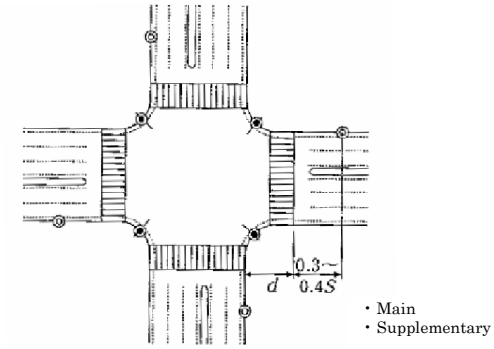
Photo 2 Intersection lighting

Table 5 Recommended brightness of intersection lighting [Standard for Road Lighting Explanation] [1]

• The average road surface illuminance should be approximately 20 Lx, with an illuminance uniformity ratio of approximately 0.4 (defined as the minimum illuminance at the road surface divided by the average road surface illuminance).
• At intersections with low traffic volume that are located in low-light environments, the recommended average road surface illuminance is 10 Lx.



• At some intersections between relatively wide roads provided with pedestrian crossings it may not be possible to provide the recommended level of brightness within the intersection. In this case, light fixtures should be installed on the corner cut-away as depicted in the diagram below.



2.2.3 Sidewalk lighting

Recent years have seen an increasing emphasis in Japan on universal design principles to facilitate the movement of people with reduced mobility, particularly elderly and disabled persons. To this end, stipulations have been added to the Standard regarding sidewalk lighting designed to ensure the safe and unhindered passage of pedestrians. Standard for Road Lighting Explanation also provides recommended brightness values for sidewalk lighting (average road surface illuminance of at least 5 Lx, illuminance uniformity ratio of at least 0.2). Table 6 provides details from the Standard and Standard for Road Lighting Explanation.

In locations of particular importance with higher numbers of elderly and disabled persons, the provisions of Table 7 in Guideline of Road structure for smooth movement [2] are taken as reference.

Photo 3 Sidewalk lighting

Table 6 Sidewalk lighting standards [1] [2]

［Standard for Road Lighting］ Sidewalk lighting is designed to provide a proper visual environment to ensure the safe and unhindered passage of pedestrians at night. ［Standard for Road Lighting Explanation］ [1] Sidewalk lighting should ensure the safe passage of pedestrians along the sidewalk by providing sufficient illuminance to enable identification of obstacles, steps and other features on the sidewalk surface. Road surface illuminance should ideally be no less than 5 Lx, taking into consideration the traffic volume and lighting environment. Given that variance in brightness levels at the sidewalk surface can impede vision, the illuminance uniformity ratio at the sidewalk surface should ideally be at least 0.2. Light fixtures should ideally be configured at regular intervals in a continuous pattern to provide optimum guidance.

Table 7 Stipulation in barrier-free guidelines

［Explanation of Design Guidelines to Facilitate Movement along Roadways］ Taking into consideration the characteristics of elderly and disabled persons, the brightness level required to ensure safe, secure and unhindered passage is an average road surface illuminance of 10 Lx.

3. NILIM study of road surface illuminance and light fixture configurations in intersection lighting systems

3.1 Analysis of the effect of intersection lighting in reducing traffic accidents

NILIM conducted an analysis of the effect of intersection lighting in reducing traffic accidents at 18 intersections on arterial roads, using the traffic accident statistics database maintained by Ministry of Land, Infrastructure, Transport and Tourism. The analysis looked at the ratio of night-time accidents before and after installation of lighting and calculated the differences. Field surveys were conducted to determine the average road surface illuminance at each of the 18 intersections.

Table 8 shows the analysis findings. At intersections where the average road surface illuminance was 20 Lx or greater, the ratio of night-time accidents decreased. At 30 Lx or greater, a statistically verified significant difference of 1% was obtained. These results demonstrate that intersection lighting of 20 Lx or greater is effective in reducing accidents. [3]

Table 8 Ratio of night-time accidents by illuminance level [3]

Average road surface illuminance	Ratio of night-time accidents (accidents per 100 million vehicles)			Statistically verified difference (before versus after)	Analysis sites
	before installation	after installation	Difference		
Less than 20 Lx	12,071	15,797	3,726	-	5
20 Lx to less than 30 Lx	15,602	9,485	-6,117	-	7
30 Lx or greater	20,180	5,098	-15,082	1% statistically significant	6

NB: The accident ratio is the sum of multiple analysis sites.

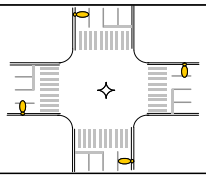
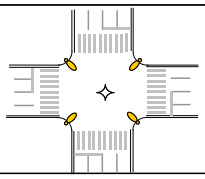
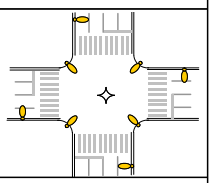
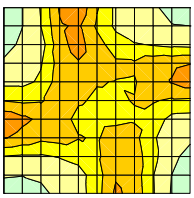
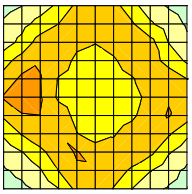
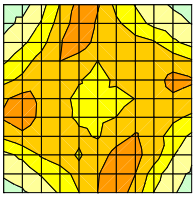
3.2 Experiments on average road surface illuminance and light fixture configurations in intersection lighting systems

Experiments were conducted at designated experimental intersections to determine the required road surface illuminance and optimum configuration of light fixtures in intersection lighting systems.

The experiments evaluated visibility of pedestrians from the perspective of the vehicle driver under various combinations of three road surface illuminance values between 5 and 20 Lx and three configurations of light fixtures, as shown in Table 9. Column A shows the configuration stipulated in the old Standard for Road Lighting Explanation, while column B shows the result from light fixtures installed on the corner cut-aways of the intersection. Column C represents a combination of A and B. The analysis also tested various locations for both pedestrians and drivers. Drivers were asked to evaluate the visibility of pedestrians under each set of conditions using a five-point rating scale.

Figure 1 shows the “acceptable ratio” for each set of experimental conditions, which is defined as the proportion of drivers who nominated response 3 (“These conditions are acceptable”) on the five-point scale. At an average road surface illuminance of 10 Lx or greater, the acceptable ratio was over 70%. Acceptable ratios for B and C configurations (light fixtures installed on corner cut-aways) were almost the same as for configuration A. [4]

Table 9 Light fixture configurations used in experiment [4]

Configuration	A	B	C
Light fixture configuration			
Illuminance distribution in intersection			

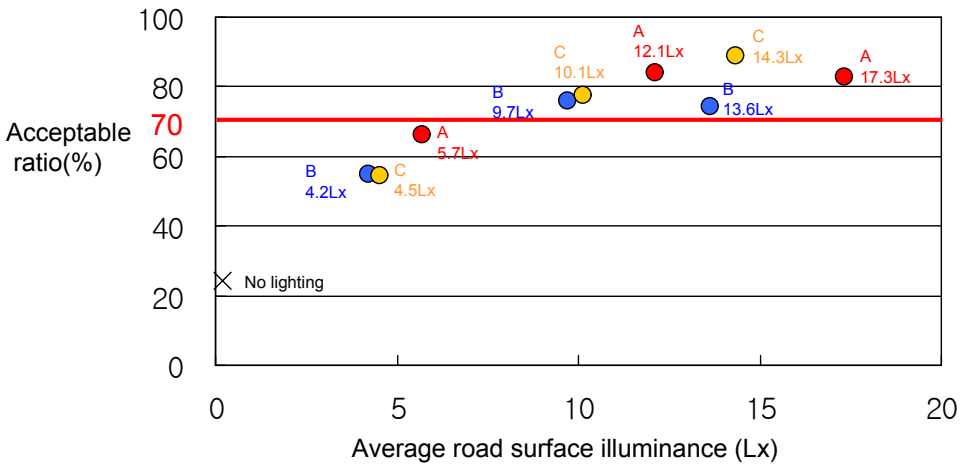


Figure 1 Acceptable ratio for each combination of experimental conditions [4]

3.3 Study of recommended values for average road surface illuminance and light fixture configurations

The study of road surface illuminance values and light fixture configurations was conducted with reference to the results from 3.1 and 3.2.

The analysis of road lighting on arterial roads found that an average road surface illuminance of at least 20 Lx works to reduce the incidence of traffic accidents. This is the same as the average road surface illuminance value of 20 Lx for C2 roads (major urban arterial road intersections) given in CIE Technical Report 155 [5]. The study produced a recommended value of approximately 20 Lx for average road surface illuminance at intersections. The visibility evaluation tests, meanwhile, found that a minimum average road surface illuminance of 10 Lx provides adequate visibility at intersections. It was therefore decided to adopt a minimum average road surface illuminance figure of 10 Lx for all intersections, including those with low vehicle and pedestrian traffic in low-light environments (and those with good visibility conditions). The minimum illuminance uniformity ratio for intersection lighting was 0.4, again based on CIE Technical Report 155.

With regard to the configuration of light fixtures, the visibility evaluation tests suggested that lighting installed on corner cut-aways provided adequate visibility. Accordingly, a corner cut-away configuration was added to the configuration provided in the old Standard for Road Lighting Explanation (column A in Table 7).

Table 10 Lighting requirements in conflict areas（CIE115-1995）[5]

Lighting Category	Min. Maintained Illuminance	Uniformity Ratio of Illuminance
C0	50 Lx	0.4
C1	30 Lx	
C2	20 Lx	
C3	15 Lx	
C4	10 Lx	
C5	7.5 Lx	

4. NILIM study of road surface illuminance in sidewalk lighting systems

An experiment was conducted on a designated experimental sidewalk to determine the required road surface illuminance in sidewalk lighting systems. In the experiment, various obstacles were placed on the sidewalk. Subjects were asked to negotiate the sidewalk and to assess the visibility of the obstacles. Subjects were divided into foot pedestrians (further divided into elderly and non-elderly categories), cyclists, and wheelchair users. Five levels of road surface illuminance were used: 20 Lx, 10 Lx, 5 Lx, 3 Lx and 1.5 Lx.

Table 11 shows the findings from the experiment. The “Can see steps and obstacles” evaluation item elicited a Yes response from nearly all subjects in all categories (foot pedestrians, cyclists and wheelchair users) at all levels of road surface illuminance. “Can see road surface and proceed without difficulty” was rated highly at illuminance of 5 Lx or greater; at 3 Lx and below, however, it was rated poorly among foot pedestrians (particularly in the elderly category) and cyclists, with over 70% of subjects in these categories giving a No response. These results suggest that foot pedestrians, cyclists and wheelchair users require a road surface illuminance of at least 5 Lx in order to correctly identify steps and obstacles on the sidewalk. [6]

The item “Can see faces of approaching pedestrians” rated poorly at illuminance for wheelchair users of 5 Lx and below, as did “Feel in danger from approaching pedestrians” at 3 Lx and below. These results suggest that a road surface illuminance of at least 10 Lx is required to ensure safe and secure passage of wheelchair users.[6]

Uniformity of illuminance should be no less than 0.2 Lx, based on the Technical Standards from the Illuminating Engineering Institute of Japan [7].

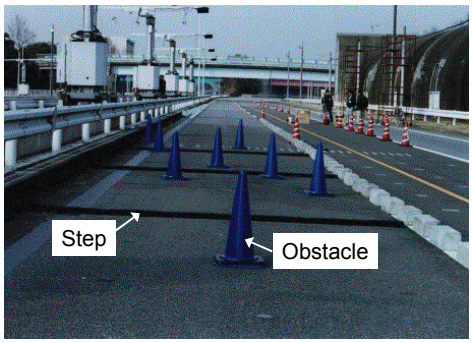


Photo 4 Experimental sidewalk

Photo 5 Experiment in progress

Table 11 Sidewalk lighting evaluation results [6]

Evalution items \ Subjects	Foot Pedestrians (Elderly)	Foot Pedestrians (Non-elderly)	Cyclists (Non-elderly)	Wheelchair users
Can see steps and obstacles	20 lx 9 0 10 lx 10 0 5 lx 10 0 3 lx 10 0 1,5 lx 8 2 0% 25% 50% 75% 100%	20 lx 10 0 10 lx 10 0 5 lx 10 0 3 lx 10 0 1,5 lx 10 0 0% 25% 50% 75% 100%	20 lx 10 0 10 lx 10 0 5 lx 10 0 3 lx 10 0 1,5 lx 10 0 0% 25% 50% 75% 100%	20 lx 7 0 10 lx 7 0 5 lx 7 0 3 lx 7 0 1,5 lx 0% 25% 50% 75% 100%
Can see road surface and proceed without difficulty	20 lx 9 0 10 lx 10 0 5 lx 10 0 3 lx 9 1 1,5 lx 7 3 0% 25% 50% 75% 100%	20 lx 10 0 10 lx 10 0 5 lx 9 1 3 lx 3 7 1,5 lx 1 9 0% 25% 50% 75% 100%	20 lx 10 0 10 lx 10 0 5 lx 10 0 3 lx 3 7 1,5 lx 3 7 0% 25% 50% 75% 100%	20 lx 6 1 10 lx 7 0 5 lx 7 0 3 lx 6 1 1,5 lx 0% 25% 50% 75% 100%
Can see faces of approaching pedestrians	20 lx 16 2 10 lx 15 5 5 lx 13 7 3 lx 7 13 1,5 lx 4 16 0% 25% 50% 75% 100%	20 lx 20 0 10 lx 20 0 5 lx 14 6 3 lx 3 17 1,5 lx 0 20 0% 25% 50% 75% 100%	20 lx 19 1 10 lx 20 0 5 lx 12 8 3 lx 4 16 1,5 lx 0 20 0% 25% 50% 75% 100%	20 lx 14 0 10 lx 12 2 5 lx 5 9 3 lx 3 11 1,5 lx 0% 25% 50% 75% 100%
Feel no danger from approaching pedestrians	20 lx 16 2 10 lx 18 2 5 lx 15 5 3 lx 16 4 1,5 lx 16 4 0% 25% 50% 75% 100%	20 lx 20 0 10 lx 20 0 5 lx 19 1 3 lx 16 4 1,5 lx 15 5 0% 25% 50% 75% 100%	20 lx 20 0 10 lx 19 1 5 lx 16 4 3 lx 14 6 1,5 lx 8 12 0% 25% 50% 75% 100%	20 lx 14 0 10 lx 14 0 5 lx 13 1 3 lx 12 2 1,5 lx 0% 25% 50% 75% 100%

■ YES □NO

5. Conclusions

This Report has described the main changes in the revised Standard for Road Lighting, as well as the studies and experiments performed by NILIM in relation to the revisions. Previously, the Standard for Road Lighting stipulated specifications such as the height and spacing of light fixtures. The new Standard stipulates performance requirements of lighting systems. It is hoped that this change of approach will facilitate the early adoption of new lighting technology, thereby promoting the development of safer and more effective road lighting systems.

NILIM has conducted various studies and investigations on road lighting systems and other forms of traffic safety facilities, the results of which have been incorporated into Japanese national standards. NILIM is committed to continuing its investigations to enable the development of safe and effective traffic safety initiatives in the future.

REFERENCES

1. Japan Road Association. Standard for Road Lighting Explanation. 2007.10
2. Japan Institute of Construction Engineering. Guideline of Road structure for smooth movement. 2008.2
3. Hiroshi Ohya, Kazuhiko ANDO, Hideyuki Kanoshima, A study of Road Lighting Measures that Reduce Nighttime Traffic Accidents, Proceedings of 2000 Annual Conference of the Illuminating Engineering Institute of Japan, pp119, 2000.8
4. Kunihiko Oka, Keiichi Ikehara, Osamu Minoshima, Takashi Kawai, Noboru Inukai. Study on Requirements of Intersection Lighting. Technical Note of National Institute for Land and Infrastructure Management. 2006.2
5. Commission International de l'Eclairage. CIE Recommendations for lighting for motor and pedestrian traffic. CIE Technical Report115. 1995
6. Kazuhiko Ando, Kentaro Hayashi, Nozomu Mori. Study of Intensity of Illuminance Required by Pedestrian Lighting, Commission International de l'Eclairage 2003 Meeting, 2003.6
7. Illuminating Engineering Institute of Japan, Technical Standards of JIEC-006, Standard of public lighting for pedestrian, 1994